

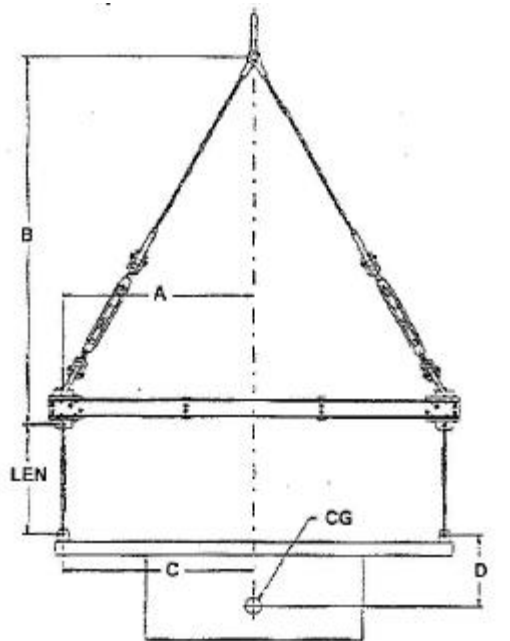
Lift Stability Analysis

Ilene Sokolsky

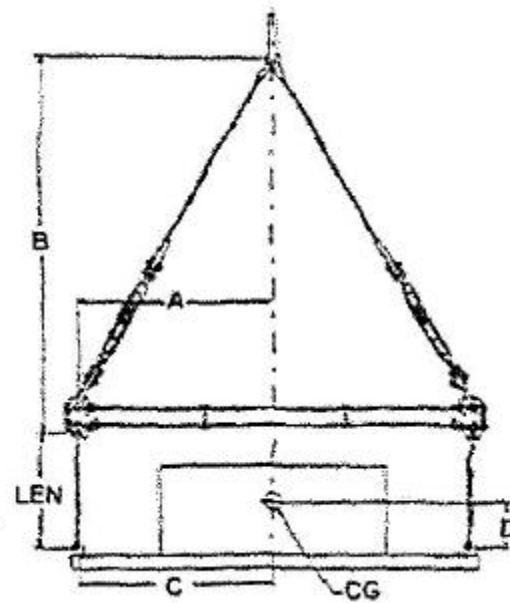
April 1, 2004

Lifting Above vs. Below Load CG

- Above CG - inherently stable
- Below CG - may or may not be stable



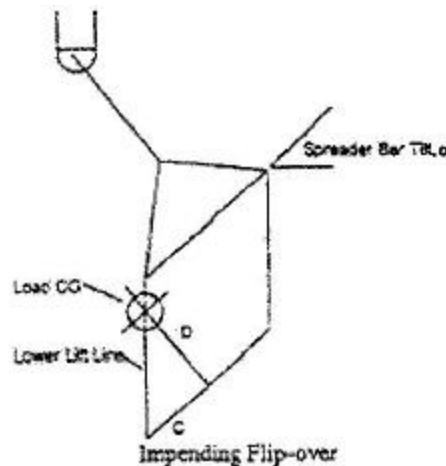
Above CG lift



Below CG lift

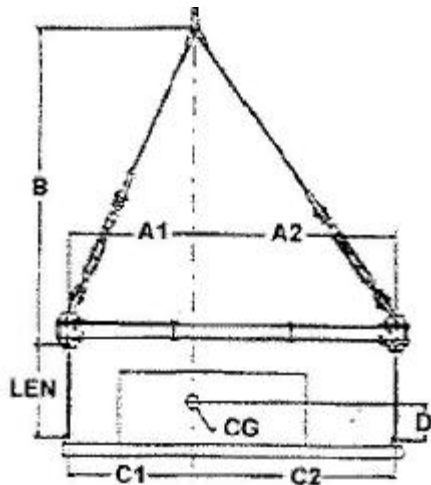
What Happens When a Lift Becomes Unstable?

- The lift becomes unstable when tipping or swinging causes the load CG to shift such that it is vertically in line with the lower lift point



Lift Directly Above CG

- Symmetric lift - CG in geometric center of load
- Asymmetric lift – CG not in geometric center of load

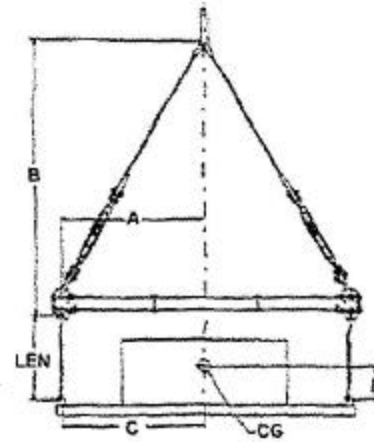


Asymmetric Lift

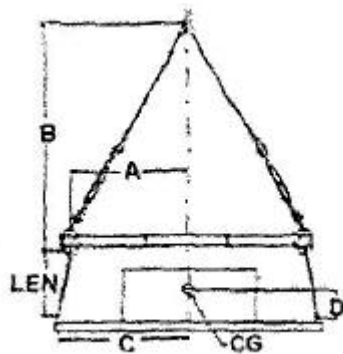
Upper lift point must be directly above the CG, whether the lift is symmetric or asymmetric

Types of Lifts

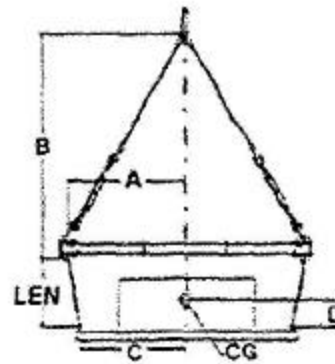
- Parallel Lift
- Umbrella Lift
- Birdcage Lift



Parallel



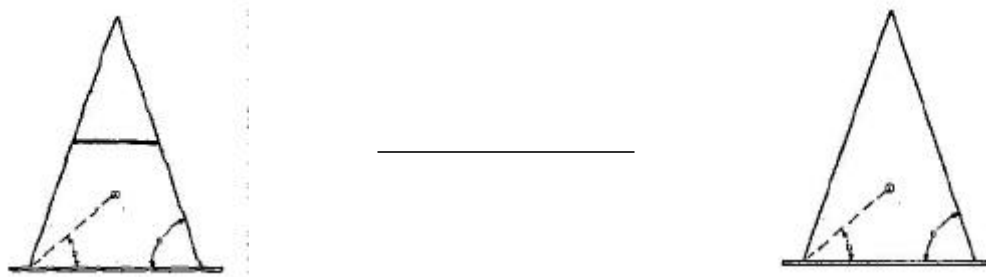
Umbrella



Birdcage

Relative Desirability of each Lift Type

- Umbrella lift is the most stable
- Parallel lift is the second most stable
- Birdcage lift is the least stable



In this case, remove spreader bars. Lift stable as long as load CG is within boundary of cables

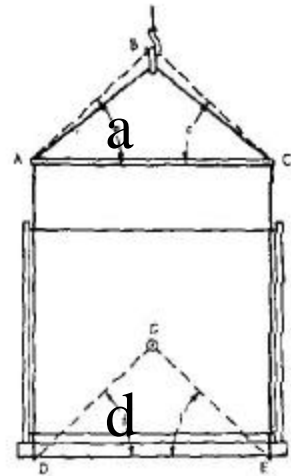
How to Determine Whether Lift is Stable – Backup Documents

- “Will the Load Tip?” by J.A. Churchill and R.F. Schoof, Allis Chalmers Electrical Review, 4th Quarter 1962
- “Spreader Bar Stability,” JPL Document JPL D-6904, Appendix G, most recent revision effective 3/29/2001
- “Analysis Procedure for Spreader Bar Lift Stability,” NSI Document Number 15-01-422, April 6, 1993

How to Determine Whether the Lift is Stable – Churchill & Schoof

- It is recommended that the base angles of the suspension triangle be planned so that they are approximately 50 percent greater than the load center-hitch point triangle base angles

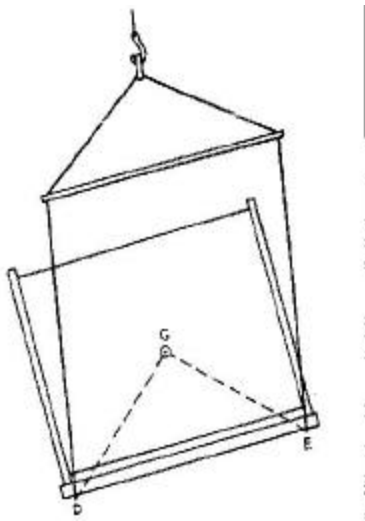
$$a = 1.5 * d$$



- Further Limitation: If base angle is 10° or less, it is further recommended that the height of the suspension triangle be made at least 12" greater than the height of load center-hitch point triangle

Churchill & Schoof, Cont'd

- Neutral stability: when suspension triangle and load center-hitch point triangle are similar



Rotation about the CG in neutral equilibrium can continue with no tendency to return; CG remains in line with lift hook rather than lifting as the sling swings

- To avoid neutral stability, use a safety factor of 1.5 to yield the formula from the previous slide

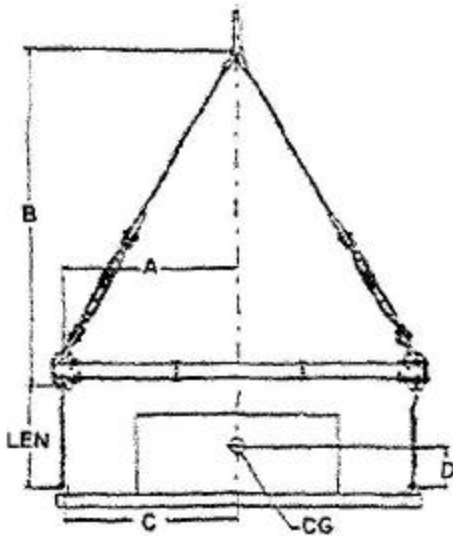
Churchill & Schoof, Cont'd

- Formula applies to parallel lifts only
- Graphical procedure given for umbrella and birdcage lifts
 - For umbrella lifts, formula will give a conservative result, so it can still be safely used
 - For birdcage lifts, graphical formula provides a method for deriving the worst-case (?) position of the load and sling when you assume a 15° spreader bar angle; if the CG moves up in this position, you have a quantitative measure of the lift stability
 - Assume that 15° angle is based on experience of what a worst-case spreader bar tile might reach
 - Avoid birdcage lift if possible

How to Determine Whether the Lift is Stable – JPL

- From JPL document:

$$B = (A^2/C^2) * 1.5 * D$$



Neutral Equilibrium at $B=D$ (for parallel lift case where $A=C$)

Safety Factor of 1.5

A^2/C^2 reduces safety factor of 1.5 for umbrella lifts; increases it for birdcage lift

JPL, Cont'd

- Comparing JPL and Churchill & Schoof formulas shows that in parallel case, results very similar to about 18° spreader bar angle; above this, JPL gives less conservative results
- JPL formula applicable to all three lift types, but document presents same graphical procedure as Churchill & Schoof, so we assume that they recommend checking birdcage results with graphical procedure
- Along with Churchill & Schoof, they recommend avoiding the birdcage if possible

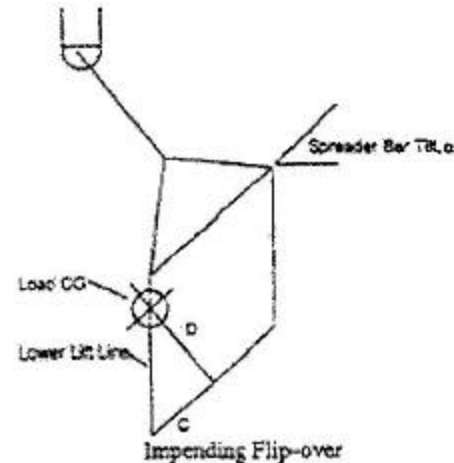
How to Determine Whether Lift is Stable - NSI

- JPL formula re-affirmed, though additional analysis methods added because certain loads (tall, thin loads) might pass the JPL stability criterion but still be unstable
- Flipping criterion added. Instead of limiting analysis to 15° spreader bar tilt, check the angular excursion which causes the load to flip over

NSI, Cont'd

- For parallel lifts, flipping criterion is:

- $a_{\text{flipover}} = \tan^{-1}(C/D)$
- Flipping angle should be some reasonable large number so the lift has a large tolerance for handling (NSI recommends rule of thumb: crane will not impart enough energy to reach flipover angle as long as $C > 2 \cdot D$; translates to $a_{\text{flipover}} = 63.4^\circ$; this extremely conservative number seems quite high – use judgment to accept lower numbers between 15° and 63.4°)



NSI, Cont'd

- For umbrella lifts, if a little excess conservatism is okay, use formula for parallel lifts
- For birdcage lifts, use graphical procedure from Churchill & Schoof or JPL and keep raising the spreader bar tilt angle until tipping point is identified

NSI, Cont'd

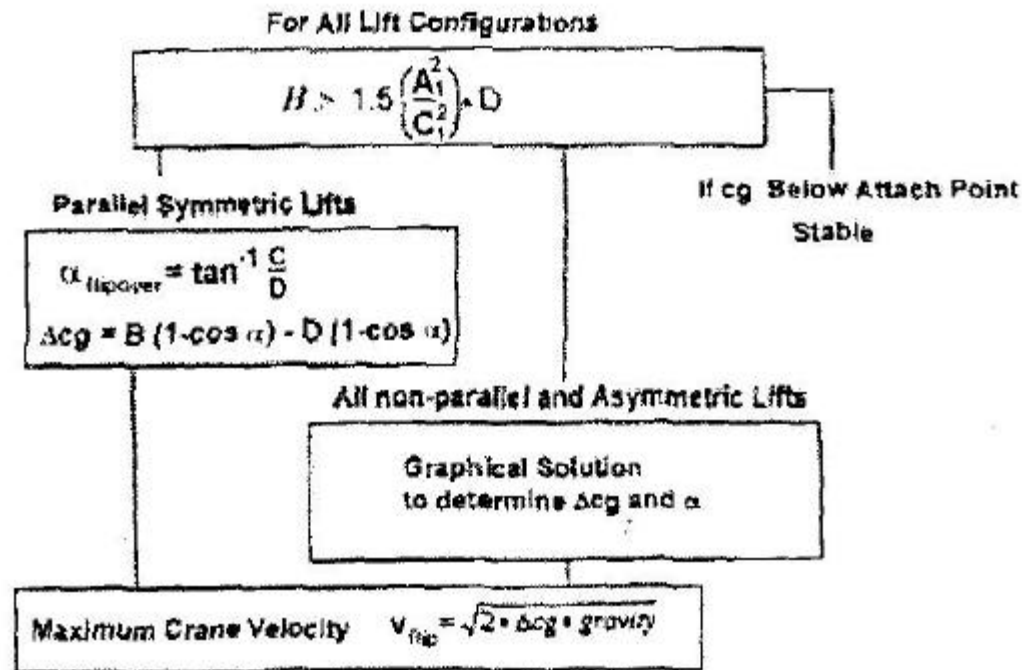
- NSI also used energy methods to derive a formula for calculating the maximum crane speed for a safe lift:

$$- V_{\text{flip}} = \sqrt{2 * \Delta CG * gravity}$$

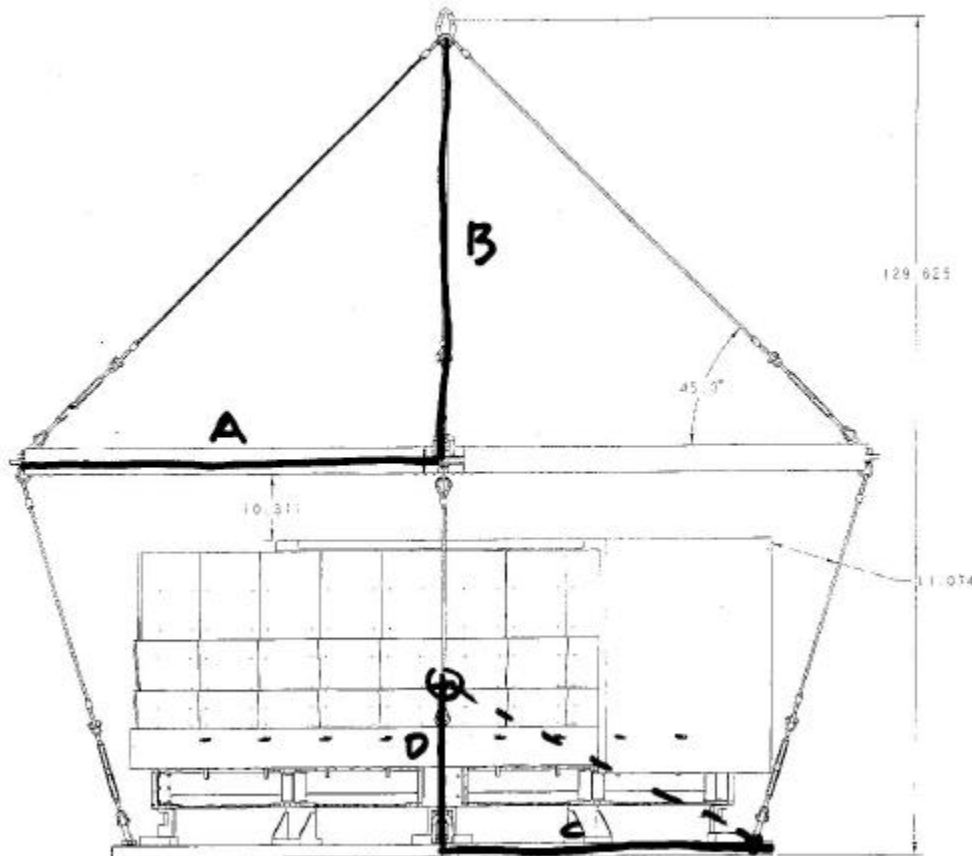
- Where $\Delta CG = B(1-\cos\alpha) - D(1-\cos\alpha)$ for parallel lifts and ΔCG is calculated using graphical solution for birdcage lifts

NSI, Cont'd

- NSI Analysis Summary



Example – Lifting ACD Plus Vibe Plate



A=46"

B=68"

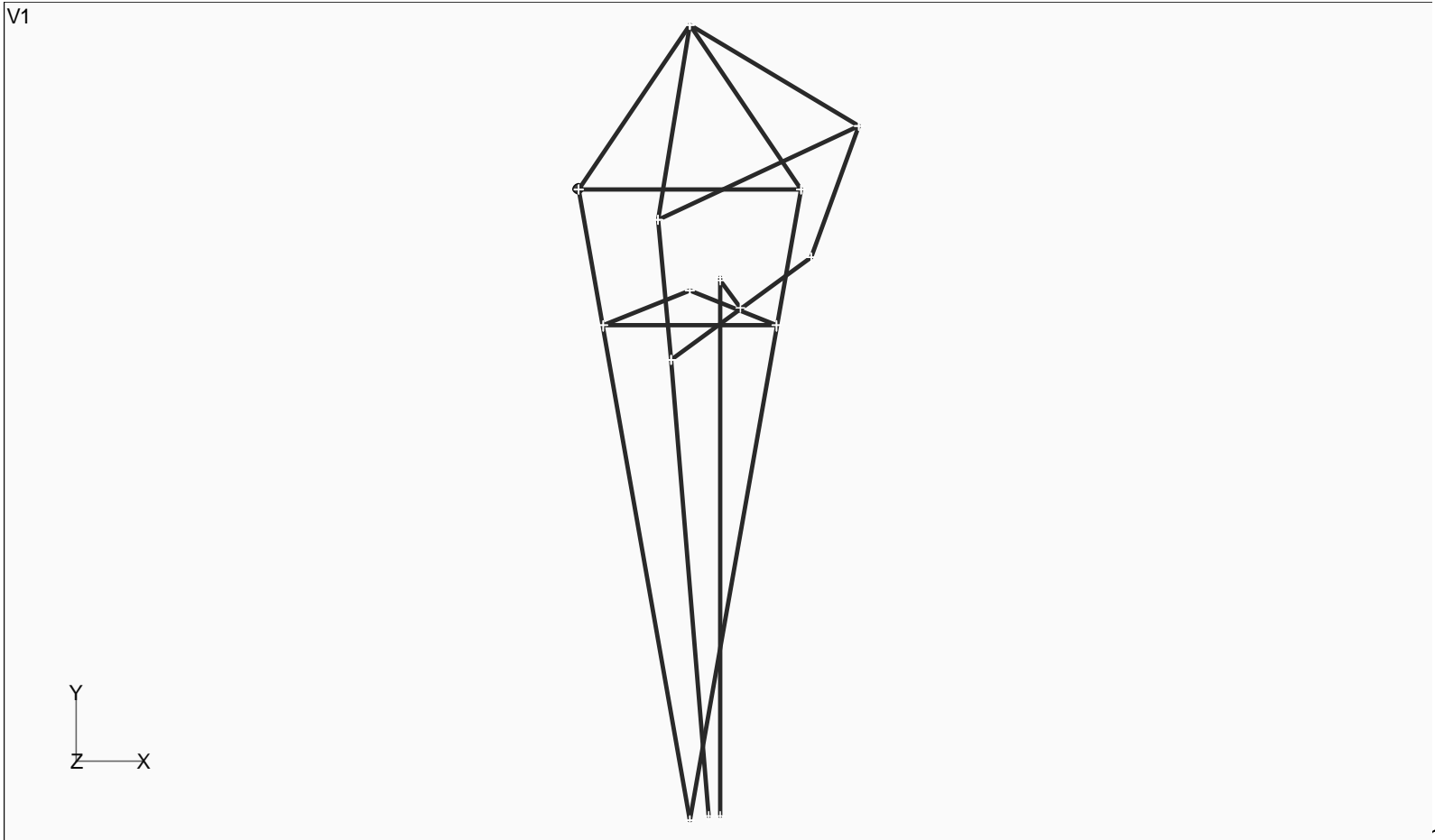
C=36"

D=14.7"

Example, Cont'd

- Is lift hook directly above the CG? Yes
- Does this example meet JPL Stability Formula?
 - $1.5 * D * A^2 / C^2 = 36.0$
 - $B = 68$
 - $B > 1.5 * D * A^2 / C^2$: Criterion met
- Does this example meet NSI Tipping Formula?
 - Attempted graphical method – worked at 25° and gave a positive D_{CG} with no tipping. Failed to work at 50° , gave up after numerous iterations
 - If lift were parallel, tipping angle would be 67.8° , implying a large tipping angle for birdcage case as well

Example, Cont'd (Graphical Method)

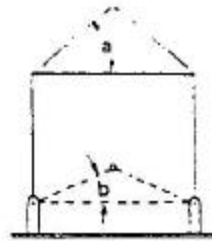


Example, Cont'd

- What is max crane velocity?
 - Without ΔCG , cannot calculate max crane velocity
- Is Lift Stable
 - Yes
 - We meet JPL stability criterion
 - We know from graphical method that we're far from tipping at 25°
 - We don't have a tall, thin load with a high CG

What If You Don't Have a Stable Lift?

- Increase Dimension B (vertical distance of lift hook to upper spreader bar)
- Reduce Dimension D (vertical distance between load CG and lowest lift points)



- Make lower platform rigid to spreader bar by use of cross bracing or cross members

Future Work

- Non-linear finite element analysis to determine more accurately when load will dump based on relationship between swing and tip